Explaining seasonal fluctuations of infectious diseases in Africa using existing nighttime lights imagery

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We are an academic team interested in mapping human movement and its affects on the movement of pathogens
Our expertise include human infectious disease dynamics and mathematical modeling. We also have geographical expertise, specifically in remote sensing techniques, GIS, spatial analyses, and environmental modeling.

Infectious disease epidemics in West Africa represent a significant proportion of vaccine-preventable childhood mortality. The mechanisms underlying the observed strong seasonal fluctuations in incidence have been poorly understood, hindering immunization efforts. We have found evidence that changes in population density drive seasonal measles dynamics. We have developed a novel approach to measure seasonal changes in anthropogenic light using satellite imagery and thereby assess spatiotemporal fluctuations in population density. We find that measles transmission rates and population density are highly correlated. With dynamic disease models, we demonstrate that measures of local population density are essential for predicting epidemic progression and optimizing intervention strategies. In addition to epidemiological applications, the ability to measure fine-scale changes in population density has implications for public health, crisis management, and economic development.

Figure 1
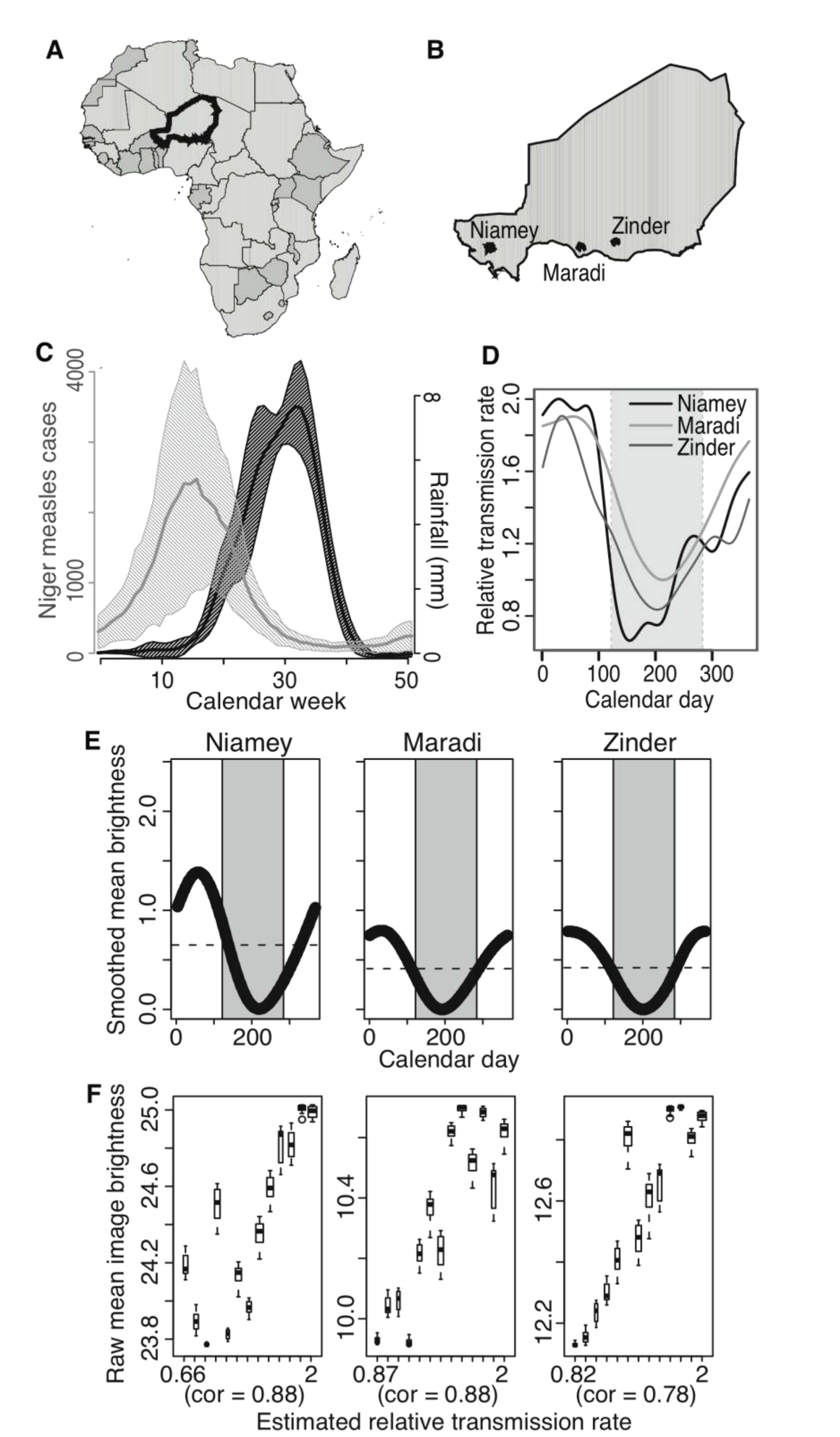
A) Map of Africa, Niger outlined in black
B) The three cities of Niger highlighted in this study.
C) Average weekly annual rainfall for Niger in mm from 2003-2006 (dark grey) and national weekly average of annual measles cases from 1995-2004 (light grey). Shaded area represents 95% confidence intervals, x-axis shows calendar week 1-52.
D) Relative transmission rates for three urban areas (Niamey (black), Maradi (light grey), Zinder (dark grey)), estimated from reported cases over ten years . Gray shaded area indicates rainy season, x-axis shows calendar day 1-365. Niamey has the greatest range in transmission rate, followed by Zinder and Maradi.
E) Smoothed (df = 3) relative brightness by day of year for each city. Gray shaded area indicates rainy season, dashed horizontal lines indicate mean of brightness for each city, x-axis shows calendar day 1-365. Niamey has the greatest range in brightness, followed by Zinder and Maradi (table S1.1).
F) Boxplots of brightness by city against estimated relative transmission rate. Width of box plots correlates to number of observations.

Figure 2
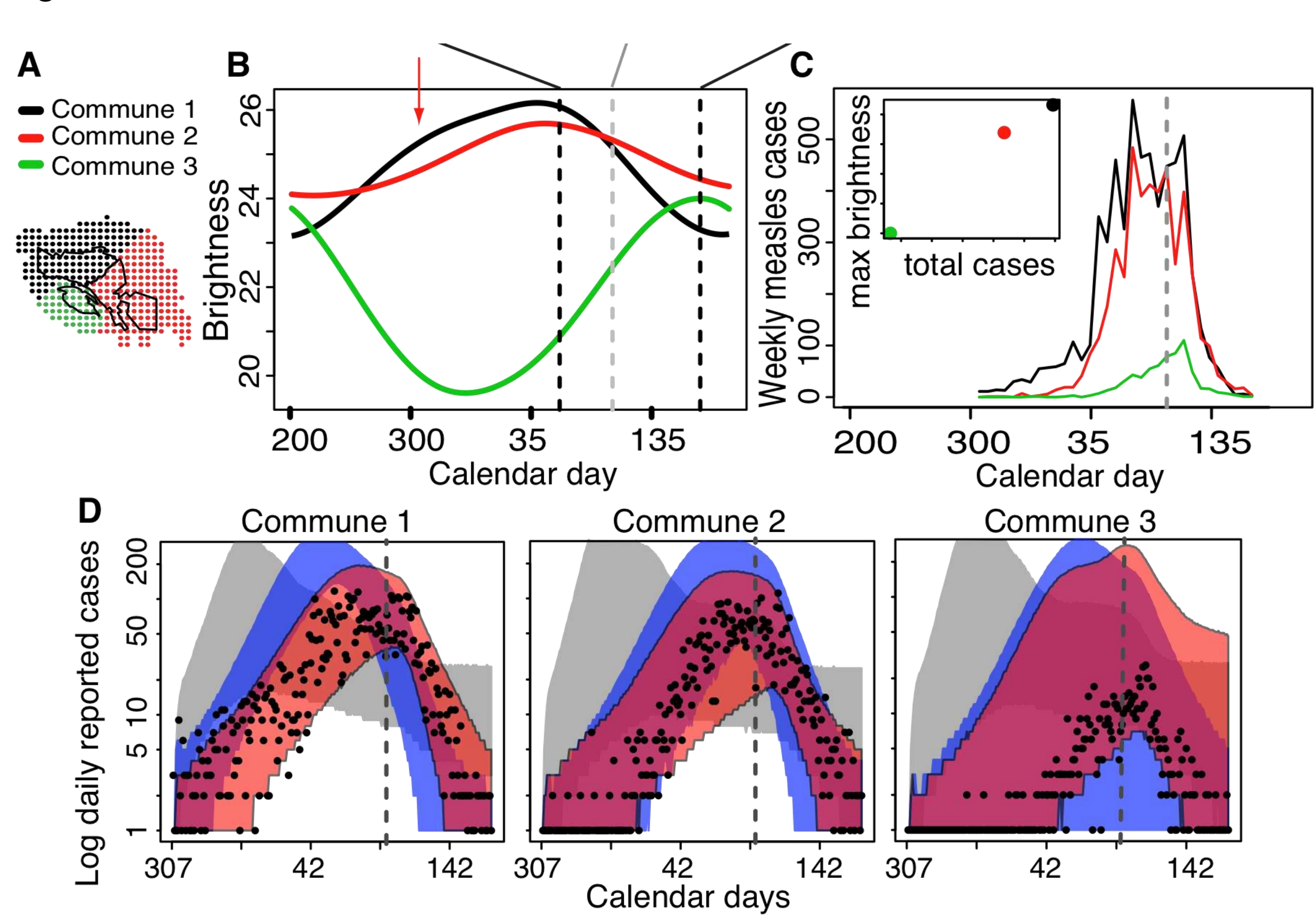
A) Pixels of Niamey showing commune designations by color. Black polygons show outlines of communes.
B) Plot: Smoothed (df = 3) brightness of each commune plotted against day of year, colors as in **A**. Vertical dashed lines indicate peak of measles epidemic in commune 1 (black, left), timing of ORI (grey), and peak of rainy season (black, right). Red arrow indicates beginning of measles epidemic in commune 1. X-axis shows 365 calendar days, starting at day 200.
C) Reported measles cases aggregated by week for each commune, colors as in **A**. X-axis shows 365 calendar days, starting at day 200. Inset: The maximum brightness values of each commune plotted against the total number of measles cases.
D) Reported and predicted measles cases under three competing models for each commune. Black dots show daily reported cases. Red area shows model predictions of measles incidence incorporating levels of immigration and emigration as indexed by nighttime light. Blue area shows model predictions of measles incidence with no immigration. Grey area shows model predictions of measles incidence with constant immigration. Shaded regions reflect the central 90% of 25000 trajectories simulated under each model from independent draws of parameter values from the posterior distribution. The dashed vertical grey line in each panel indicates the timing of the ORI. X-axis begins at calendar day 307 of 2003 and ends at calendar day 153 of 2004, spanning the exact duration of the measles epidemic and case reporting, y-axis is log of cases.

We are interested in extending the applications of these methods to current issues in public health. Our immediate goals include mapping real time changes in population density as it affects human health for single events as well as recurring scenarios. Specifically, we are interested in developing methods to map the changing sizes of refugee camps in real time to aid in humanitarian crises. We are also interested in quantifying the increase in brightness and other measures of density for known events of human aggregation that impact infectious disease dynamics, such as the annual Hajj to Mecca.

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